National Aeronautics and
Space Administration

DEEP SPACE
EXPLORATION SYSTEMS

EXPLORATION SYSTEMS DEVELOPMENT UPDATE

NASA ADVISORY COUNCIL – MARCH 26, 2018

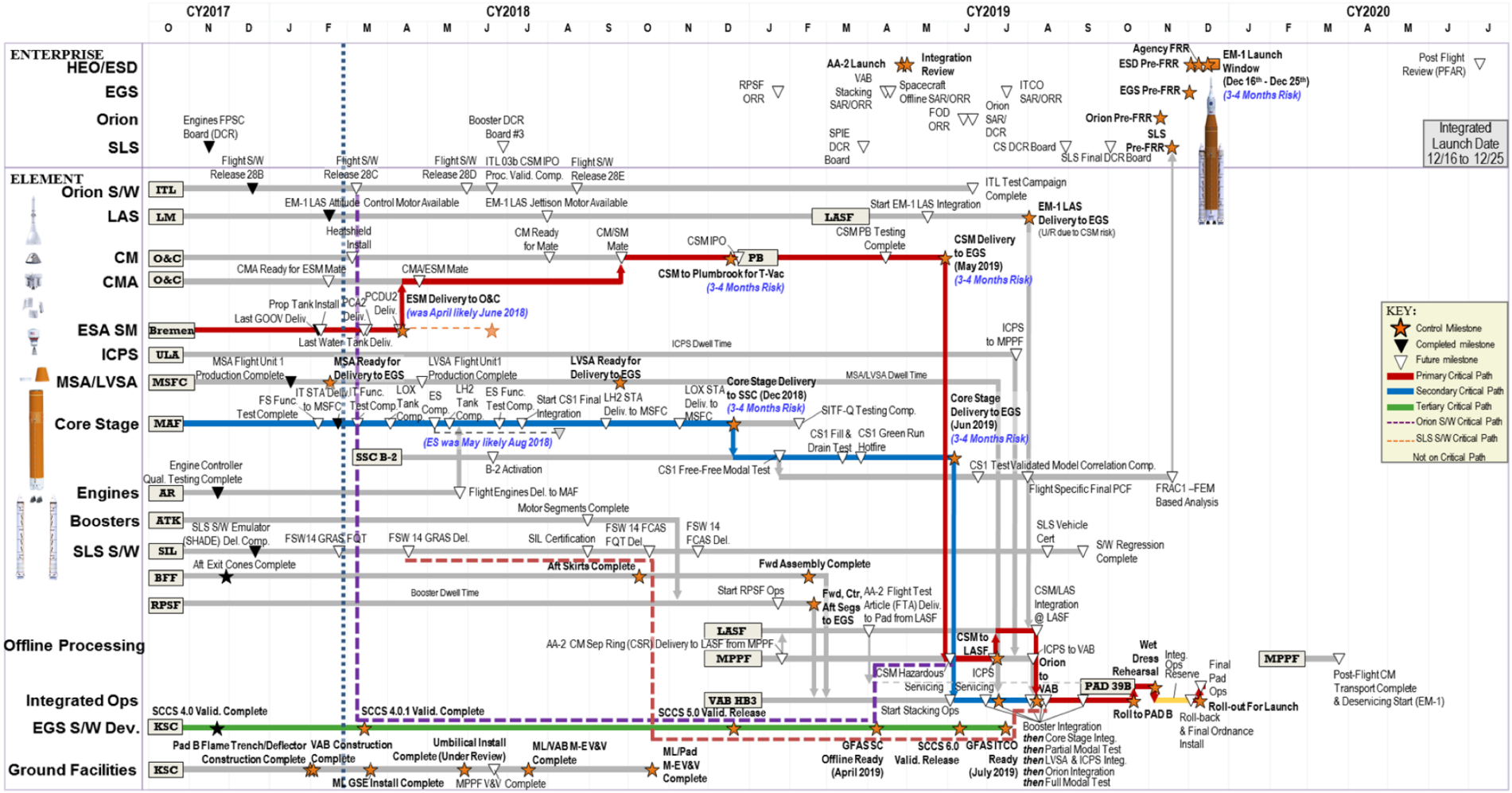
BILL HILL, DEPUTY ASSOCIATE ADMINISTRATOR
EXPLORATION SYSTEMS DEVELOPMENT

MARSHALL SMITH, DIRECTOR, CROSS-PROGRAM SYSTEMS INTEGRATION
EXPLORATION SYSTEMS DEVELOPMENT

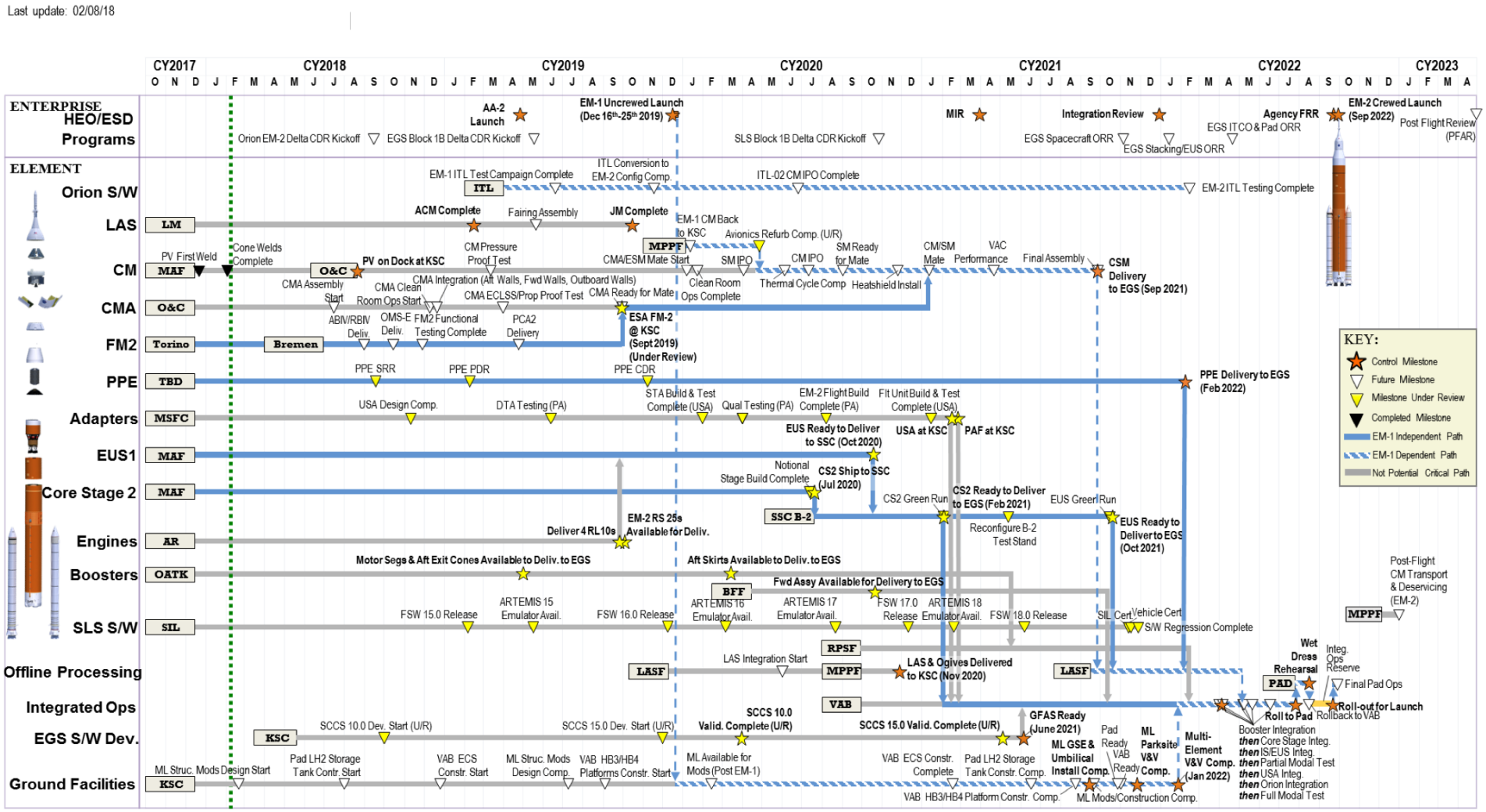
EM-1 INTEGRATED MISSION MILESTONE SUMMARY

Last update: 02/28/18

December Month End Data

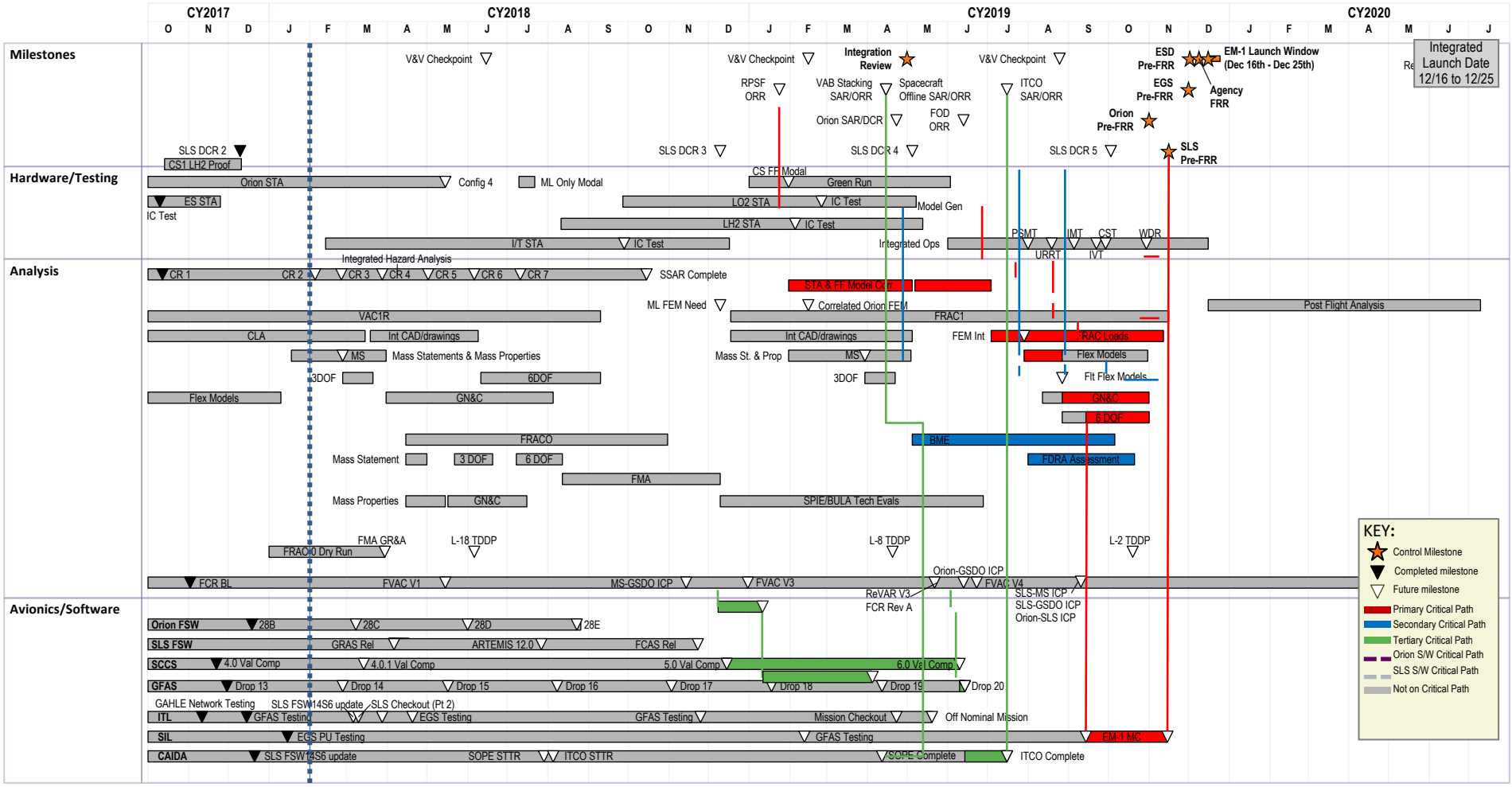


DRAFT EM-2 IMMS



EM-1 SE&I SUMMARY SCHEDULE

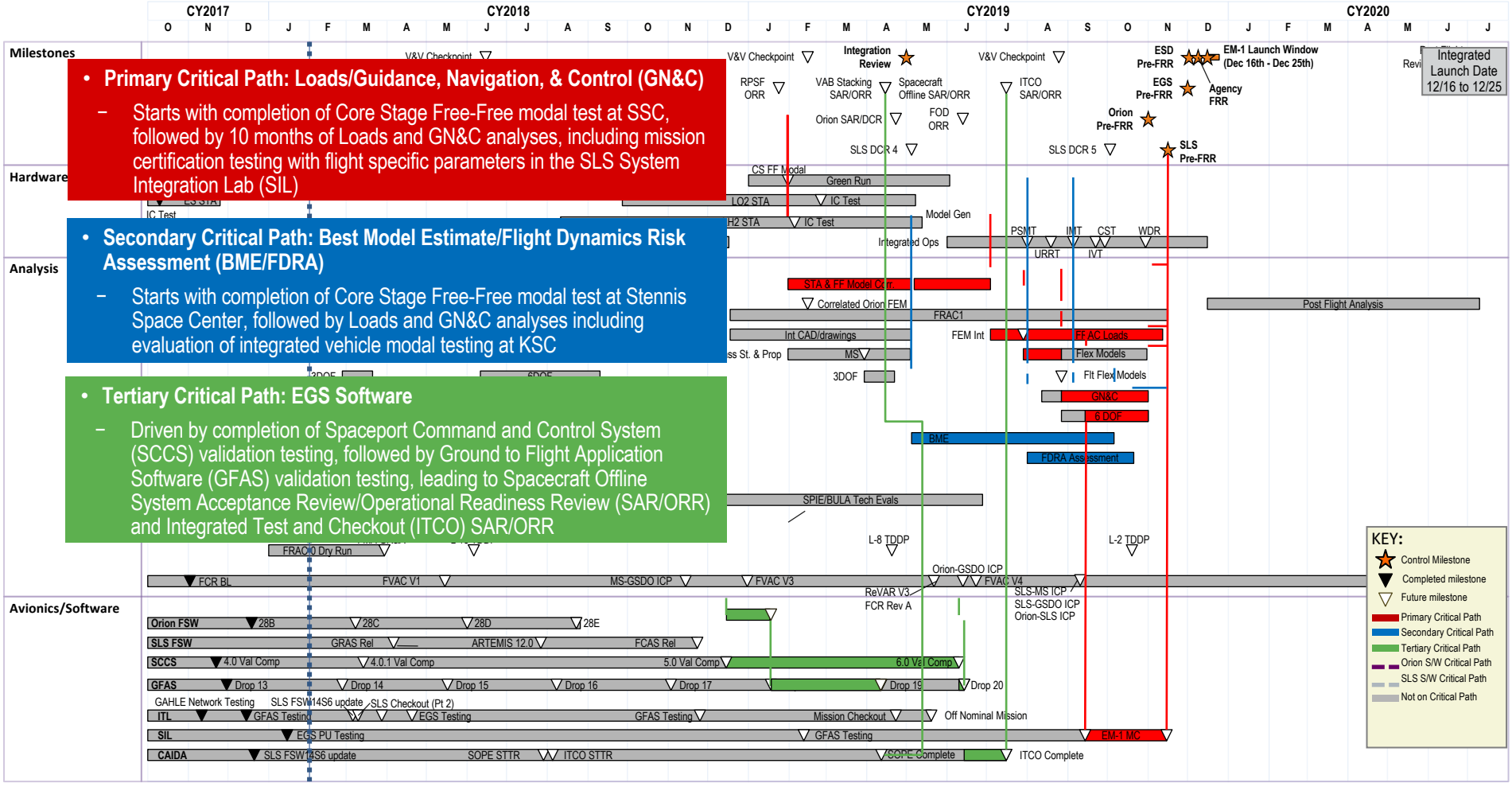
Last update: 02/01/18



EM-1 SE&I SUMMARY SCHEDULE

Last update: 02/01/18

- **Primary Critical Path: Loads/Guidance, Navigation, & Control (GN&C)**
  - Starts with completion of Core Stage Free-Free modal test at SSC, followed by 10 months of Loads and GN&C analyses, including mission certification testing with flight specific parameters in the SLS System Integration Lab (SIL)
- **Secondary Critical Path: Best Model Estimate/Flight Dynamics Risk Assessment (BME/FDRA)**
  - Starts with completion of Core Stage Free-Free modal test at Stennis Space Center, followed by Loads and GN&C analyses including evaluation of integrated vehicle modal testing at KSC
- **Tertiary Critical Path: EGS Software**
  - Driven by completion of Spaceport Command and Control System (SCCS) validation testing, followed by Ground to Flight Application Software (GFAS) validation testing, leading to Spacecraft Offline System Acceptance Review/Operational Readiness Review (SAR/ORR) and Integrated Test and Checkout (ITCO) SAR/ORR



SE&I INTEGRATED ISSUES

Critical Integrated Issue Topic	Action	Current Status
Integrated Loads and Guidance, Navigation and Control (GN&C)	Ensure that structural math models are properly verified and validated in the most efficient manner possible and support the needs of EM-1 loads assessments, GN&C algorithm design requirements, and to collect data for crewed EM-2 flight.	• Enterprise has approved three modal tests designed to incrementally characterize the integrated system: Mobile Launcher (ML)-modal, Partial Stack Modal Test (PSMT), and Integrated Modal Test (IMT) • Continuing to evaluate schedule for math model characterization efforts including structural tests, loads and GN&C analyses, and Best Model Estimate (BME)/Flight Dynamics Risk Assessment (FDRA)
Orion Simulator	Fully develop and submit for approval a contingency plan to use the Orion Simulator should the actual ESM/Orion be later than planned to KSC	• Simulator requirements approved at JICB. • Developing plan forward with list of key decision dates for implementation, will bring to JICB.
Enterprise Verification and Validation	Ensure that the Enterprise Verification and Validation (EV&V) activities will not delay the launch	• Planning V&V checkpoint in June 2018 to finalize ESD, ITT, and Program expectations in integrated V&V execution and reporting • Developed integrated verification burndown metrics • Developed approach to interface verification • Engaging in Modeling & Simulation (M&S) certification effort to ensure overall V&V schedule is met (CPIT creating ad hoc M&S cert team)

SE&I INTEGRATED ISSUES

Critical Integrated Issue Topic	Action	Current Status
Core Stage Assembly, Integration and Test (AI&T)	Increase SE&I focus and engagement on Core Stage (CS) AI&T issues that could impact the EM-1 integrated schedule (e.g. late hardware delivery impacts to Green Testing schedule and subsequently to CS, SLS and ESD verification)	• Core Stage remains critical path driver for SLS; critical path is through Engine Section Integration • Schedule challenges due to late parts & work instruction redlines
Green Run Testing	Increase SE&I focus and engagement on Green Run planning and execution that could impact the EM-1 integrated schedule	• Schedule is success-oriented; assumes minor traveled work from MAF, limited weather delays; nominal margin for non-conformances or first time operations • Evaluating potential traveled work between SSC and KSC
ESA Service Module (ESM)	Increase SE&I focus and engagement on ESM issues that could impact the EM-1 integrated schedule	• Working closely with Orion to understand key schedule drivers that may affect the Enterprise
Vehicle Assembly, Integration and Test (AI&T)	Oversee and manage the EM-1 AI&T flow	• Working with EM-1 flow director to understand schedule and identify and pursue opportunities
Integrated Software	Ensure that all major software development areas are integrated and ready to support EM-1	• Working to ensure that software content, emulator capability, OMRS/LCC dependencies, and testing schedules are aligned

SE&I INTEGRATED ISSUES

Critical Integrated Issue Topic	Action	Current Status
Pad Stay Time	Resolve hardware problems and requirements related to pad stay time across the Enterprise	• Discussing load spectrum; Orion hardware testing in progress; cleaning up requirements
Fracture Control	Develop list of hardware with fracture control problems or where testing is costly in comparison to the risk reduction provided	• Working with Orion and SLS programs and chief engineers to collect list of hardware with fracture control problems • Collecting list of EM-1 variances to fracture control requirements
Integrated Trajectories	Review trajectory analysis plans and ensure trajectories are ready to support Flight Readiness Analysis Cycle (FRAC) and final flight trajectory target generation	• Working through delivery issues • Kicking off FRAC-0 dry run • Will set Groundrules and Assumptions (GR&A) for Final Mission Analysis (FMA)/FRAC-0 in late March
Booster Throat Plug Debris	Assess and develop best approach to mitigate Booster Throat Plug Debris Impact to RS-25 Debris Risk	• Assessing Booster water nozzle down angle • Discussing potential water-debris tests • Looking at Booster nozzle throat plug redesign
Payloads	Assess and recommend best approach for payload process: approval, requirements, development and verification necessary for co-manifested, secondary and primary (cargo) payloads	• Team reviewing existing body of work regarding payloads
Mobile Launcher Stress	Resolve Mobile Launcher (ML) stress concerns, while minimizing impacts to EGS schedule and risks to flight vehicles	• EGS proceeding with design for extensible columns underneath the ML, similar to those used by Apollo • JLTT performing loads assessment, will bring to JICB

CPIT TECHNICAL FOCUS

Interim Cryo-Propulsion Stage (ICPS) Umbilical Loads:
- Initial ICPS integrated loads over hardware design loads

Launch Availability:
- Launch opportunities are limited; looking for improvements

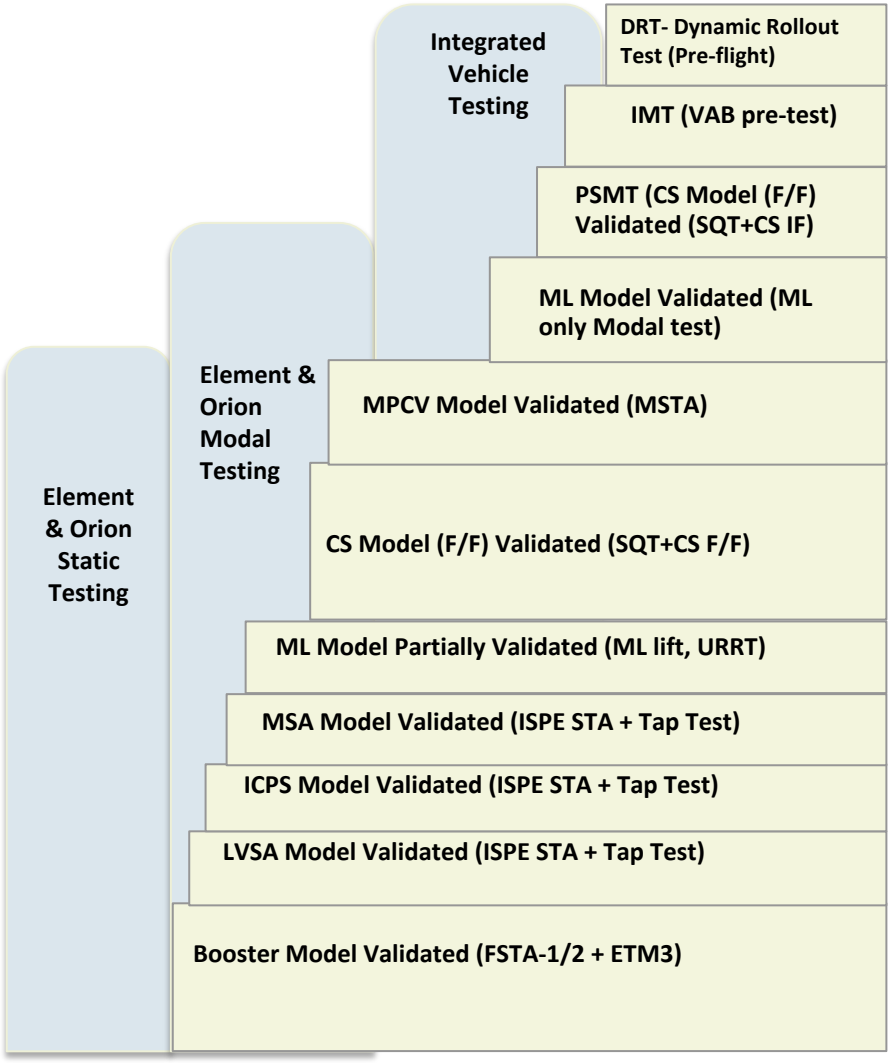
Communication uplink for EM-2 EUS:
- SLS decided not to include uplink capability for EM-2 Exploration Upper Stage (EUS) because it did not provide sufficient benefit with respect to cost

Block 1B Loads Exceed Orion Design Loads
- Block 1B Design Analysis Cycle (DAC) 1R section loads and other critical interfaces show increases over the Orion design baseline

Block 1B Vehicle Damper System Location
- Need to finalize location of vehicle damper system final location

LOADS MODEL VERIFICATION AND VALIDATION BUILDING BLOCK APPROACH

- Test-validated Element & Program structural dynamics models are used in building block approach to assemble integrated flight models
- Element & Orion static influence coefficient and modal tests are used to correlate individual element and program models and quantify the modeling uncertainty
- Integrated system level testing at KSC further quantifies the interfaces and interactions between individual elements and programs to reduce the modeling uncertainty
  - ML only Modal Test
  - Partial Stack Modal Test (PSMT)
  - Integrated Modal Test (IMT)



CORE STAGE ENGINE SECTION STA

4619 Test Stand Capabilities:

- Over 3.5M Pounds applied Vertically
- Over 1M Pounds applied Horizontally
- Isolated from High Bay Concrete
- LN2 Cryogenic Delivery System

SLS Engine Section Testing:

- Loads over 4.0M Pounds
- 55 Load Lines (up to 18” Bore Cylinders)
- Thermally Conditioned (LH^2 Simulator)
- Over 3200 Measurements

Test Stand Information:

- Area 50’ x 45’
- Height 60’

Schedule Milestones:

- 2/8/18 - All Qual and Margin Testing Complete
  - Structure passed Qual testing beyond Limit Loads.
  - Tested beyond liftoff LL at Booster interface with no structural failure noted.
- 7/1/19 - Correlated model delivery to NASA L2

CORE STAGE LIQUID HYDROGEN (LH2) STA

Test Stand 4693

Construction

- Twin tower design bridged by movable crosshead
- Built atop original Saturn V F1 engine stand foundation
- 17' thick concrete w/835 tons embedded steel foundation
- 48 feet x 48 feet x 221 feet tall

Static Load capability

- 3.25M lbs of downward axial compression force
- 2.20M lbs of upward axial tension force
- 340k lbs of north-south & east-west shear force
- 817.5M in-lbs of bending moment force
- 30k lbs tangential & 22k lbs radial force available at both 100' & 150' approx. elevations

Fluids

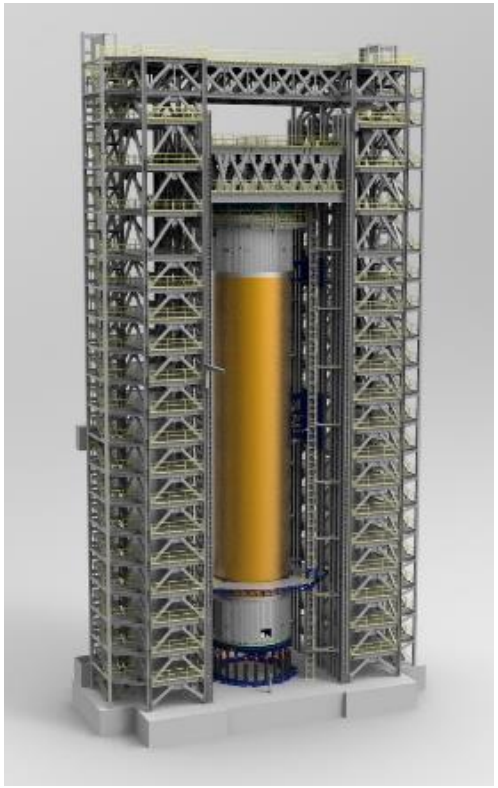
- 450k gals stored cryogenic liquid nitrogen (LN_2)
- Gaseous nitrogen pressurization/purge gas
- Gaseous high-purity air (HPA) & helium

Instrumentation

- 3400+ strain gauges
- 270 deflections measurements
- 130+ temperature & pressure sensors
- 8 microphones & 24 video cameras
- 76 load measurements

Test Systems

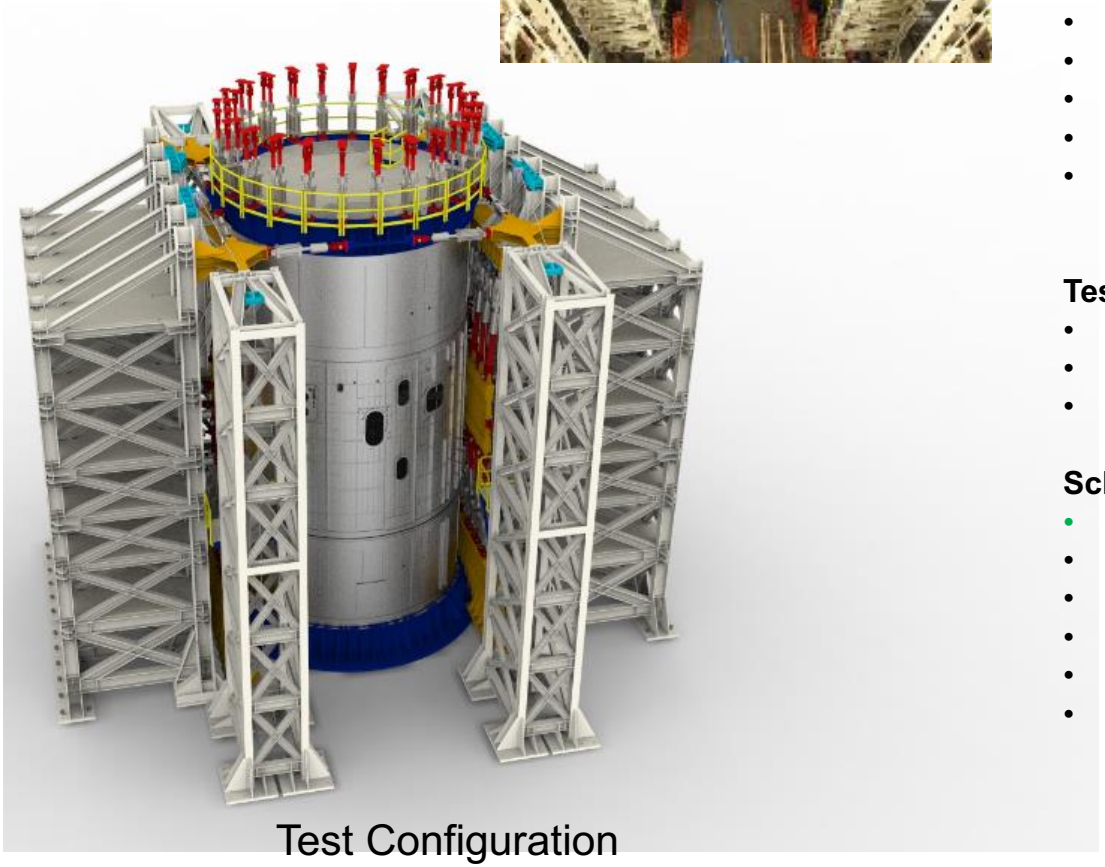
- 160 ton center hoist / 2 ton jib hoists (4)
- Test article flood lighting
- Mast climbing work platforms w/approx. 150' max elevation
- Lightning protection & electrical grounding grid
- Generator backed up 110v/208v/480v power
- 42' x 50' concrete mounting pad w/threaded hole anchor grid



LH2 Test Schedule Milestones

- 09/15/18 - Test article at TS4693
- 10/22/18 - T/A installed in stand
- 02/20/19 - Test Readiness Review
- 03/08/19 - Test Start
- 03/29/19 - CS GR Test Cases Complete
- 06/07/19 - CS DCR Test Cases Complete
- 7/1/19 - Correlated model delivery to NASA L2

CORE STAGE INTERTANK STA



Test Configuration

4619 LTA Facility Capabilities:

- Built in the 1960's
- Moveable Crosshead
- 30M Pound Loading Capacity
- 27' Thick Concrete Floor to React Loads

SLS Intertank Testing:

- Expect Loads over 11 M Pounds
- Thermally Conditioned
- Over 2200 Measurements Planned
- 48 Tests are Planned
- Additional "Margin Testing" planned following certification test series.

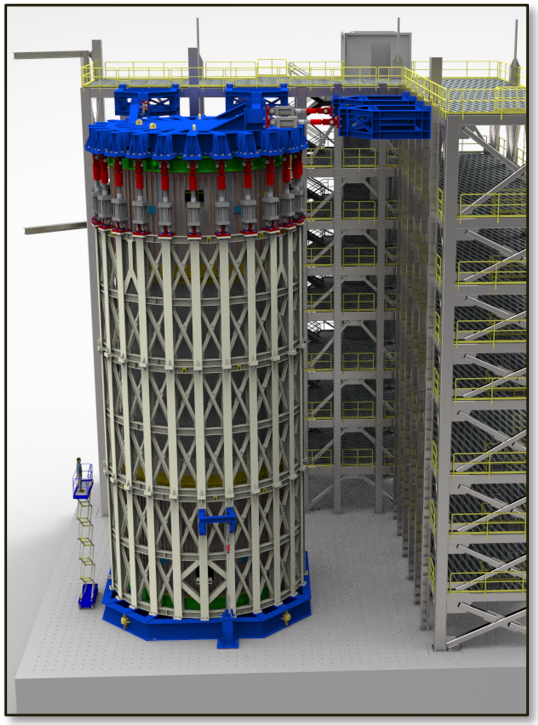
Test Configuration Facts:

- Area 60' x 60'
- Height ~62'
- Over 2M Pounds of Structural Steel

Schedule Milestones:

- 3/3/18 - Article at 4619
- 9/6/18 - Test Readiness Review
- 10/10/18 - Test Cases Complete for CS WDR
- 10/15/18 - Test Cases Complete for CS GR
- 1/3/19 - Test Cases Complete for DCR
- 7/1/19 - Correlated model delivery to NASA L2

CORE STAGE LIQUID OXYGEN (LOX) STA



4697 Facility Capabilities:
- Completed in 2016 to Support SLS Program
- Concrete Floor to React Loads
- Outdoor Test Facility
- Cryogenic System (LN^2/LH^2)

SLS LOX Tank Testing:
- 34 Load Lines Apply Liftoff & Ascent Loads
- LOX Tank Thermally Conditioned with LN^2
- Bonded Heat Strips will Simulate SRB Heating
- Over 2500 Measurements Planned
- 24 Tests are planned
- Additional “Margin Testing” planned following certification test series

Test Stand Information:
- Area ~36’ x ~36’
- Height ~82’

Schedule Milestones:
- 11/10/18 - Article at 4697
- 2/7/19 - Test Readiness Review
- 6/12/19 - Test Complete

ICPS INTEGRATED STRUCTURAL TEST

- Test performed February to May 2017
  - Orion Spacecraft Adaptor
  - Interim Cryo Propulsion Stage (ICPS)
  - Launch Vehicle to Stages Adaptor (LVSA)
- The test article successfully withstood all limit, ultimate, and margin load cases with no signs of detrimental deformation, rupture, or collapse
  - Obtained dynamic characterization
  - Load tested article to ultimate load levels
  - Loaded ICPS to beyond limit load (margin tests)
  - Obtained compartment acoustic characteristic

ICPS Test Article in Test Stand

SLS STA TESTING SUMMARY

- ✓ Complete Integrated Spacecraft and Payload Element Structural Test - April 2017
- ✓ ES Structural Test Article (STA) ready to ship - April 2017
- ✓ Core Stage Pathfinder Delivered - October 2017
- ✓ ES STA structural test complete - November 2017
- ✓ IT Test Facility ready - November 2017
- ✓ IT STA ready to ship - February 2018
- – LH2 STA ready to ship - August 2018
- – LO2 STA ready to ship - September 2018
- – IT STA structural test (Wet Dress Rehearsal Run) begin - October 2018
- – LO2 STA structural test (Design Certification Review Run) begin - January 2019
- – LH2 STA structural test (Green Run) begin - March 2019

Core Stage Pathfinder Delivered

Intertank STA at MAF

ISPE STA & Stand - Testing Started

Engine Section STA Stand

LH2 Tank STA Stand

LO2 Tank STA Stand

Intertank STA Stand

(Next)

Stands:	✓ ICPS/LVSA Stand Ready	✓ ES STA Stand Ready	✓ LH2 Stand CoF complete	✓ LOX Stand CoF Complete	✓ Intertank STA Stand Ready	
STAs and Testing:	✓ ICPS/LVSA STA Complete	✓ Start ICPS/LVA Testing	✓ ES STA Complete	☐ LH2 STA Complete	☐ LO2 STA Complete	☐ IT STA Complete

IT= Intertank
ES = Engine Section
ISPE = ICPS/LVSA
LVSA = Launch Vehicle Stage Adapter

ORION STRUCTURAL QUALIFICATION

Crew Module (CM) Structural Test Article (STA)

✓ Completed stiffness load test - September 2017

European Service Module (ESM) STA

✓ Completed ESM STA - August 2017

Launch Abort System (LAS) STA

✓ Completed load test - August 2017

Combined

✓ CM/SM/LAS assembly completed - December 2017

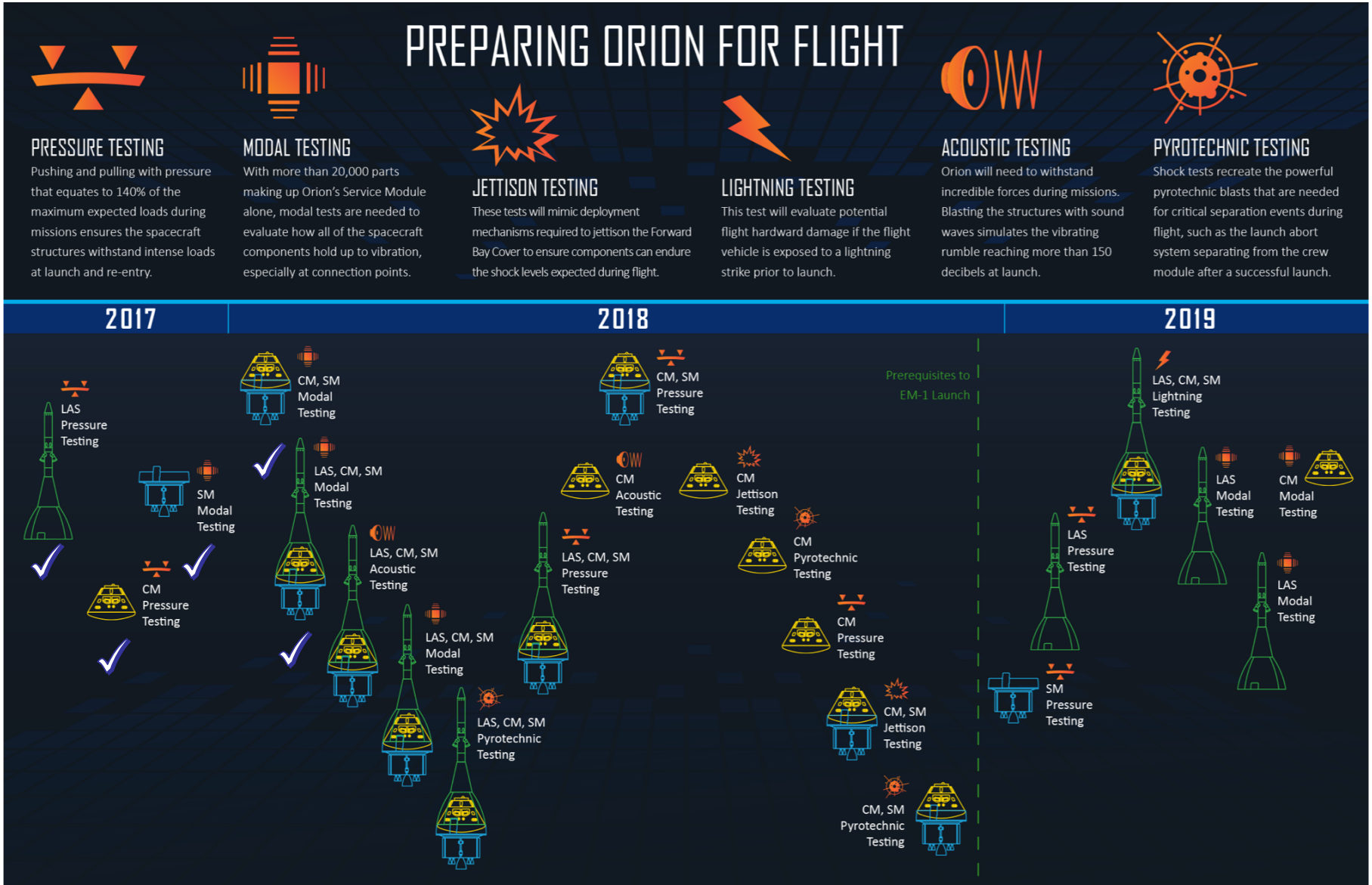
✓ Combined stack testing – modal completed - January 2018

- Combined stack testing - acoustic - May 2018
- Combined stack testing- pyro shocks - May 2018
- Forward Bay Cover jettison tests - October 2018
- EM-1 prerequisite tests complete - February 2019

Configuration 9 Test

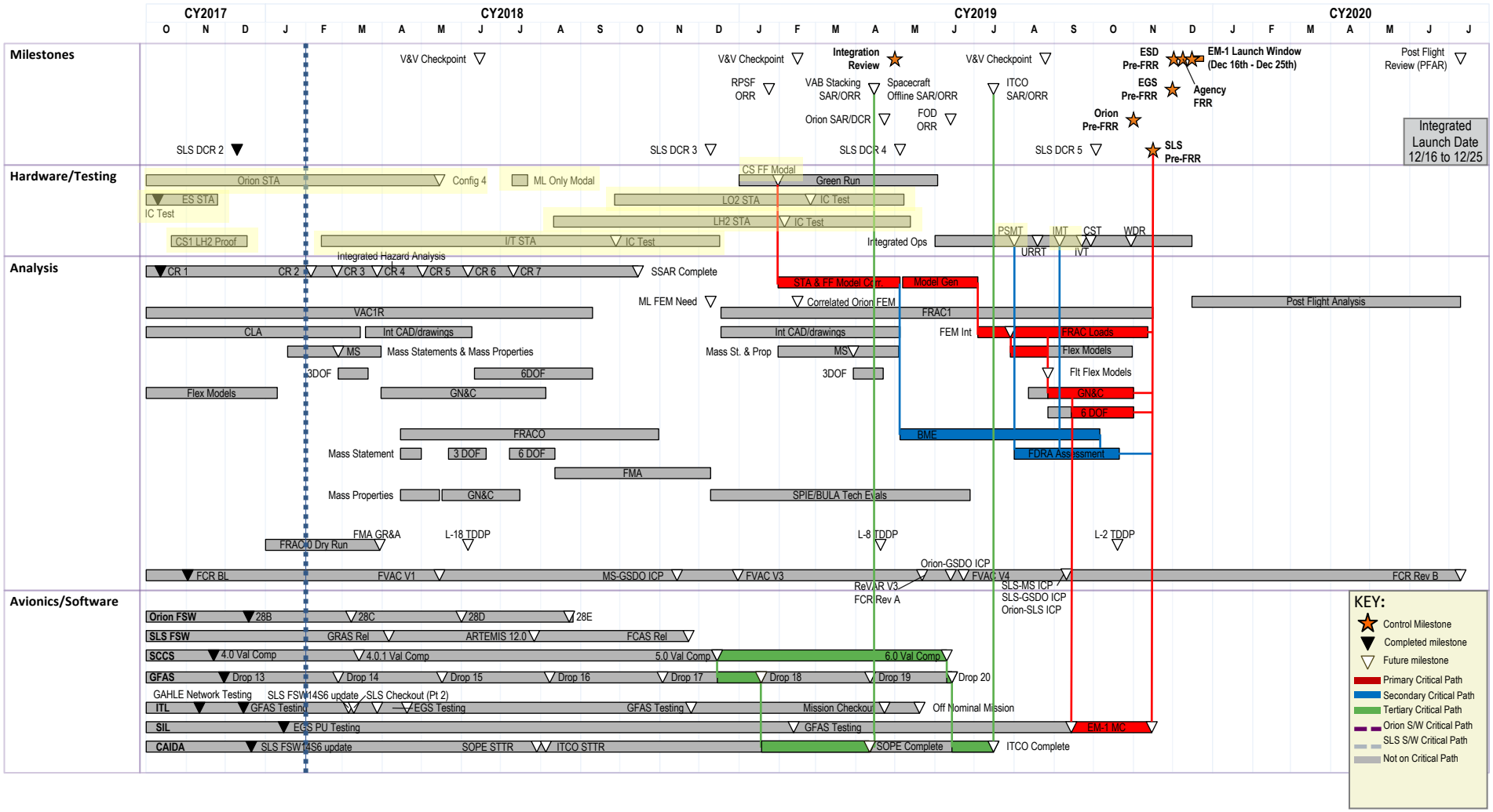
Configuration 3 Test

ORION TESTING SCHEDULE



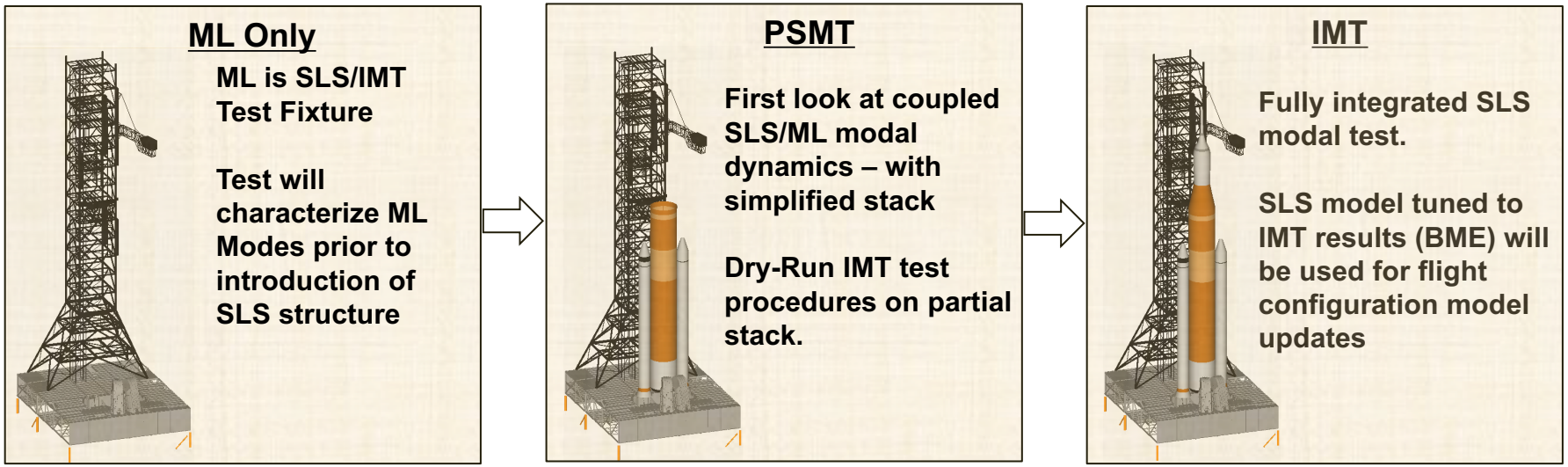
EM-1 SE&I SUMMARY SCHEDULE

Last update: 02/01/18



INTEGRATED VEHICLE MODAL TESTS

- The program has approved three modal tests designed to incrementally characterize the Mobile Launcher (ML) and SLS hardware

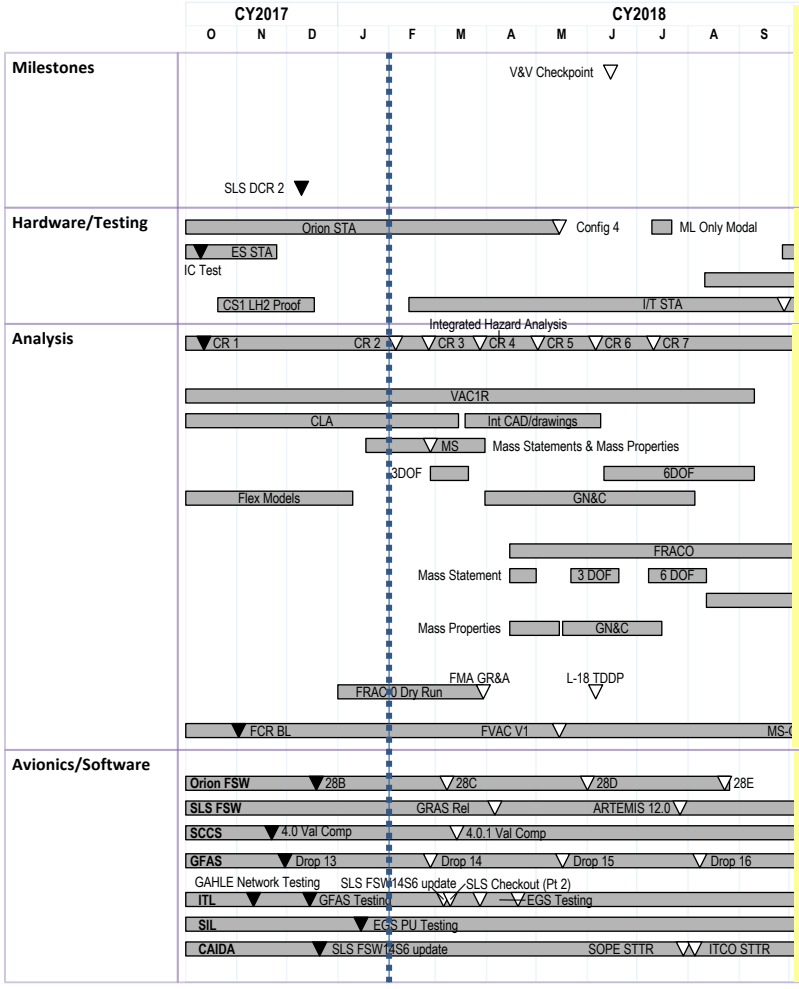


BEST MODEL ESTIMATE (BME) & FLIGHT DYNAMICS RISK ASSESSMENT (FDRA) OVERVIEW

- Best Model Estimate and Flight Dynamics Risk Assessment BME/FDRA approach will develop a suite of potential modal testing results to allow easier assessment of test results
  - Thousands of model dispersions are created from the pre-test (PSMT, IMT) models
  - Each dispersion is compared to the modal test results to determine which one best matches the test (BME)
  - The BME is projected from the test configuration to the flight configurations
  - GN&C will take the BME flight models and run a stability assessment
  - Loads will use the Orion and SLS element load transformation matrices corresponding to the pre-test models to perform a quick loads risk assessment
  - Final risk assessment will be presented at FRR

BACKUP

Cross Program System Integration (CSI) Accomplishments – Last Quarter



- Established SE&I and Integrated Mission Production and Activities Schedule (IMPAS) summary schedules to form an ESD overall schedule complement with the Integrated Mission Milestone Summary (IMMS) (Nov)
- Formed 14 SE&I teams to address critical integrated issues (Nov)
- HEO Exploration Requirements HEOMD-004 approved (Feb)

- Completed Engine Section Structural Testing (Nov)
- Completed Underway Recovery Test (URT)-6 (Jan)
- Completed 14 Integrated Comm/Network tests to verify functionality and data flows (Feb)

- ESD Functional & Operational Capabilities Closure Report (FCR) Baseline Release (Nov)
- Completed ascent loads for Verification Analysis Cycle (VAC)-1R Coupled Loads Analysis (CLA) (Jan)
- Completed VAC-1R flex models (Jan)
- Delivered VAC-1 aerothermal environments for new Outer Mode Line Protuberances
- Delivered EM-1 off-nominal loads for element and cross-program assessment (Jan)
- Block 1B Design Analysis Cycle (DAC)-2 shared compartment thermal environment analysis completed
- Closed CPIT top issue: Interim Cryo-Propulsion Stage (ICPS) Umbilical Loads (Jan)
- Delivered EM-1 Launch and Landing Mission Table for recovery planning on launch dates through December 2020 (Nov)

- Performed GSDO Advanced Hardware LCS Emulator (GAHLE) network testing in ITL (Nov)
- Performed Ground to Flight Application Software (GFAS) testing in the Integrated Test Lab (ITL) (Dec)
- Updated emulator software in Customer Avionics Interface Development and Analysis (CAIDA) lab to SLS FSW14S6 (Dec)
- Tri-Program emulator technical interchange meeting (Feb)

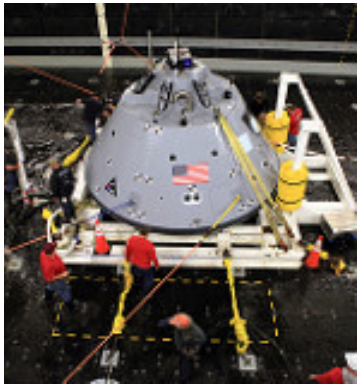
ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AA	Ascent Abort
ACM	Attitude Control Motor
AI&T	Assembly, Integration, and Testing
AIS	Aft Interstage
AM	Abort Motor
ASEU	Aft Skirt Electrical Umbilical
ASPU	Aft Skirt Pneumatic Umbilical
ATLO	Assembly, Test, and Launch Operations
ATP	Authority to Proceed
BFS	Backup Flight System
C&DH	Command and Data Handling
CAA	Crew Access Arm
CM	Crew Module
CMA	Crew Module Adapter
CMASS	Crew Module Ammonia Servicing Subsystem
CoF	Construction of Facilities
CS	Core Stage
CSFSU	Core Stage Forward Skirt Umbilical
CSITU	Core State Intertank Umbilical
CSS	Consumable Storage System
CT	Crawler Transporter
DFAT	Direct Field Acoustics Test
ECLSS	Environmental Control and Life Support System
ECS	Environmental Control System
ECU	Engine Controller Unit
EGS	Exploration Ground Systems
EM	Exploration Mission
EMI/EMC	Electromagnetic Interference and Electromagnetic Compatibility
ES	Engine Section
ESA	European Space Agency
ESD	Exploration Systems Development
ESM	European Service Module
EUS	Exploration Upper Stage
FCAS	Flight Controller Application Software
FCV	Flow Control Valve
FDIR	Fault Detection Isolation& Recovery
FIL	Fillet Panel
FM	Flight Model
FS	Forward Skirt
FSS	Fixed Service Structure
FSW	Flight Software

Acronym	Definition
FWD	Forward
GFAS	Ground/Flight Application Software
GFAST	Ground/Flight Application Software Team
GHe	Gaseous Helium
GN2	Gaseous Nitrogen
GNC	Guidance, Navigation, and Control
GO2	Gaseous Oxygen
GRAS	Green Run Application Software
GRC	Glenn Research Center
GSE	Ground Support Equipment
HB	High Bay
HF	Hot Fire
IBR	Integrated Baseline Review
ICPS	Interim Cryogenic Propulsion Stage
ICPSU	Interim Cryogenic Propulsion Stage Umbilical
IOPSS	Ignition Over Pressure and Sound Suppression
IPO	Initial Power On
ISPE	Integrated Spacecraft and Payload Element (ICPS/LVSA)
IT	Intertank
ITL	Integrated Test Laboratory
JM	Jettison Motor
KCCS	Kennedy Complex Control System
KSC	Kennedy Space Center
LAS	Launch Abort System
LEO	Low Earth Orbit
LETF	Launch Equipment Test Facility
LH2	Liquid Hydrogen
LO2	Liquid Oxygen
LOX	Liquid Oxygen
LVSA	Launch Vehicle Stage Adapter
MAF	Michoud Assembly Facility
MATA	Motor Adapter Truss Assembly
MEVV	Multi-Element Verification and Validation
MIR	Mission Integration Review
ML	Mobile Launcher
MPCV	Multi-Purpose Crew Vehicle
MPPF	Multi-Payload Processing Facility
MPS	Main Propulsion System
MSA	MPCV Stage Adapter
MSFC	Marshall Space Flight Center
N2	Nitrogen
NCA	Nose Cone Assembly

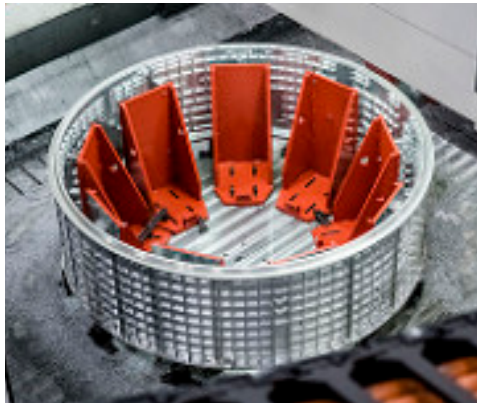
Acronym	Definition
NDE	Nondestructive Evaluation
NDS	Nitrogen Delivery System
O&C	Operations and Checkout
O/D	On Dock
OGV	Ogive Panel
OMS-E	Orbital Maneuvering System Engine
OSA	Orion Stage Adapter
OSMU	Orion Service Module Umbilical
OTP	Orion Transportation Pallet
OWG	Operations Working Group
P&O	Production and Operations
PCA	Pressurant Control Assembly
PCDU	Power Control Distribution Unit
PDU	Power Distribution Unit
PPE	Power and Propulsion Element
PQM	Propellant Qualification Model
PRT	Problem Resolution Team
PV	Pressure Vessel
QM	Qualification Motor
RCS	Reaction Control System
RWY	Raceway
SCCS	Spaceport Command and Control System
SIL	System Integration Lab
SITF	Software Integration Testing Facility
SRB	Solid Rocket Booster
SLS	Space Launch System
SSC	Stennis Space Center
STA	Structural Test Article
SW	Software
TLI	Translunar Injection
TLM	Telemetry
TPS	Thermal Protection System
TSM	Tail Service Mast
TSMU	Tail Service Mast Umbilical
TVC	Thrust Vector Control
UAS	Use As Is
ULA	United Launch Alliance
V&V	Verification and Validation
VAB	Vehicle Assembly Building
VAC	Vertical Assembly Center
VS	Vertical Stabilizer
WDR	Wet Dress Rehearsal
WSTF	White Sands Test Facility

Orion

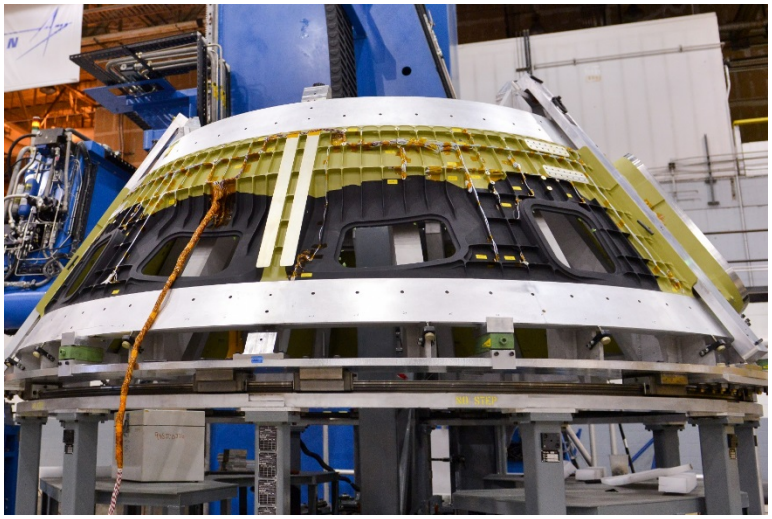


EM2

EM-2 Service Module Primary Structure



EM-2 Barrel



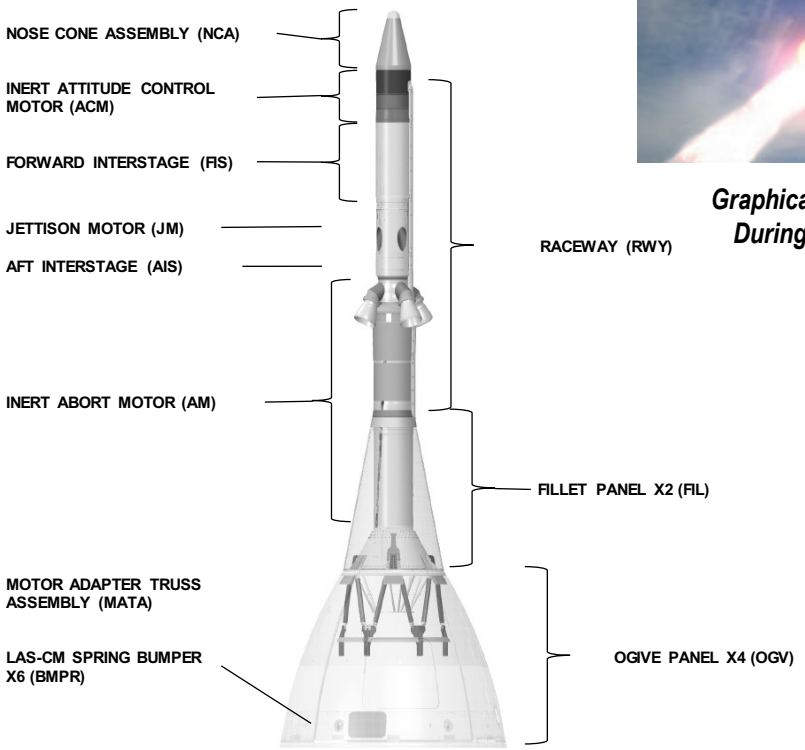
EM-2 Cone Section

EM-2 Pressure Vessel

EM-1 AND AA-2 LAUNCH ABORT SYSTEM (LAS)

(LOCKHEED)

- ✓ LAS EM-1 Fillets & Ogive panels delivered to MAF - November 2017
- – EM-1 LAS Fairing assy components ship in place - February thru July 2018
- – AA-2 LAS Jettison Motor (JM) On Dock (O/D) KSC - April 2018
- – EM-1 LAS JM delivery available - July 2018 (ship in place)
- – AA-2 LAS Fairing assy components O/D KSC - August thru December 2018
- – AA-2 LAS Attitude Control Motor O/D KSC - August 2018
- – AA-2 LAS Abort Motor O/D KSC - August 2018
- – AA-2 Launch - April 2019



Graphical Representation of LAS During AA-2 Test (scheduled April 2019)

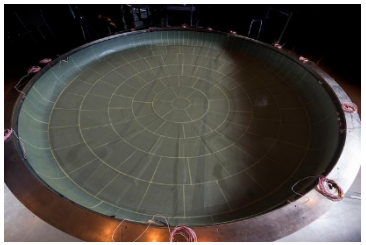
✓ Ogive & Fillet Panels Fabrication complete | EM-1 Jettison Motor Available | EM-1 Fairing components available | AA-2 Fairing components O/D KSC | AA-2 Motors O/D KSC | AA-2 Launch

EM-1 CREW MODULE (CM)

(KSC O&C BUILDING)

- ✓ CM module level test completed - November 2017
  - ✓ 28 test procedures, functionally tested all systems
- ✓ CM thermal cycle testing completed - December 2017
  - ✓ 2 full cycles, 28F to 127F
- ✓ Heatshield and Backshell fit ups completed - January 2018
- ✓ Heatshield painting and fitcheck completed - February 2018
- – Propylene Glycol Water (PGW) accumulator R&R in work
- – Heatshield Installation - March 2018 (waiting for PGW R&R)
- – Side Hatch installation & leak tests - May 2018
- – Reinstall reworked avionics (hybrid issue) - May 2018
- – CM Direct Field Acoustics Test (DFAT) - July 2018
- – CM Complete - August 2018

EM-1 CM Backshell



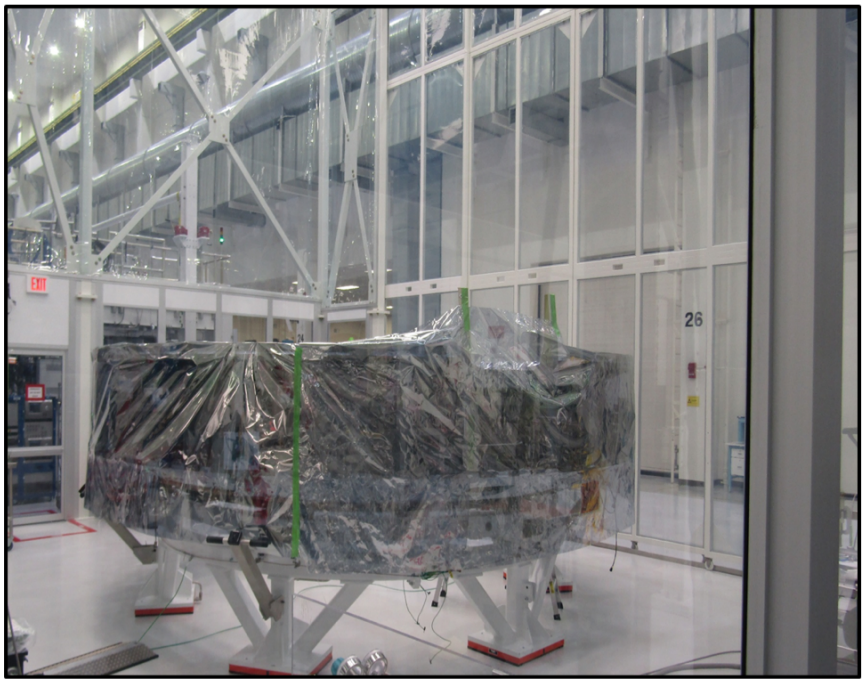
EM-1 Heat Shield Skin

EM-1 Heat Shield Painted

EM-1 CREW MODULE ADAPTER (CMA)

(KSC O&C BUILDING)

- ✓ CMA subsystem integration completed - September 2017
- ✓ CMA end-to-end testing completed - December 2017
- Temp installation of Star Trackers - April 2018
- Install T-0 flight plate - April 2018
- Reinstall reworked avionics (hybrid issue) - May 2018
- Complete functional retests - June 2018
- Ready to mate with ESM - June 2018

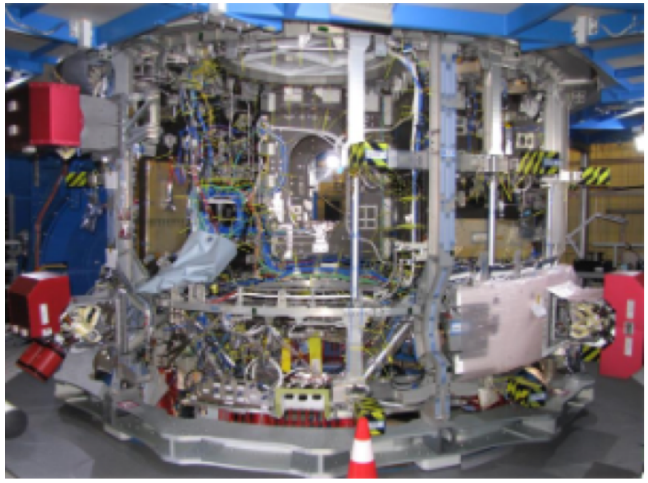


EM1 CMA in Clean Room

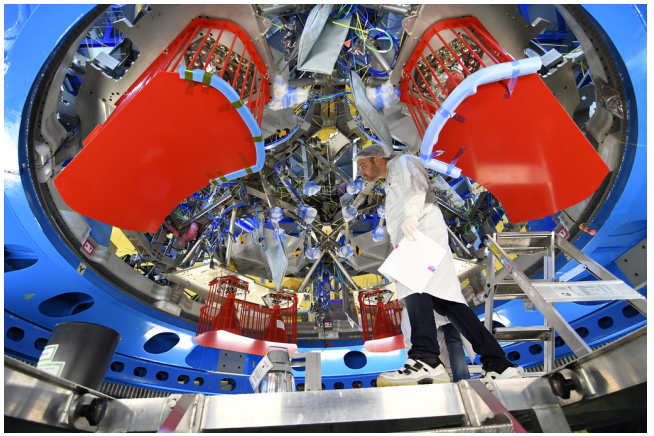
EM-1 SERVICE MODULE

(BREMEN, GERMANY)

- ✓ Installed ESM Thermal Control Unit (TCU) - June 2017 (R&R Board)
- ✓ Installed ESM Reaction Control System (RCS) Thruster - October 2017
- ✓ Pressurant Control Assembly (PCA) valves delivered to Bremen – March 2018
- – RCS Flow Control Valve (FCU) Welds (U/R)
- – ESM Power Control and Distribution Unit (PCDU) deliveries:
  - – PCDU #1 – (EM-4 then PCDU #3)
  - – PCDU #2 – (PCDU temp install, then PCDU#1)
- – ESM N2 Tank installed - March 2018 (this week)
- – ESM Prop Tanks installed - March 2018 (this week)
- – ESM Orbital Maneuvering System Engine (OMS-E) installed - March 2018
- – ESM Consumable Storage System (CSS) test complete - April 2018
- – ESM PCA final integration complete - April 2018
- – ESM Functional tests, March - June 2018
- – ESM on dock at KSC - June 2018
- – Step-1 Propellant Qualification Motor (PQM) testing complete - August 2018



ESM-1 SM Integration



ESM-1 Flight Assembly – Lower level

EM-1 CMA/ESM (KSC O&C BUILDING)

Integration Ops & Tests (KSC)

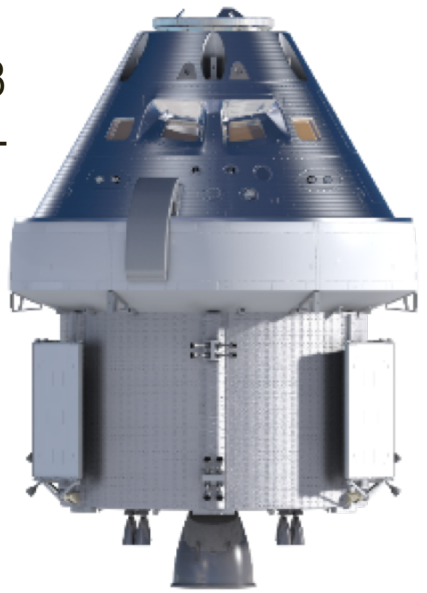
- CMA Ready to Mate - June 2018
- SM Delivery to KSC - June 2018
- CMA/ESM mate - July 2018
- CMA/ESM proof/leak test - August 2018
- SM thermal cycle test - August 2018
- SM Direct Field Acoustics Test (DFAT) - September 2018
- SM initial power up and functional tests - October 2018 – February 2019
- CM/SM Mate - December 2018

Testing (Plum Brook)

- CM/SM Transport to Plum Brook - February 2019
- CM/SM Environmental Testing (thermal vac, thermal balance, EMI/EMC) complete - June 2019
- CM/SM Transport to KSC - June 2019

Final Work (KSC)

- CM/SM Complete - July 2019
- CM/SM Turnover to EGS - July 2019



CMA/ESM Mate | CMA/ESM proof/leak test | SM initial power up/ functional tests | SM thermal cycle test | SM DFAT | CM/SM Mate

FLIGHT SOFTWARE/INTEGRATED TEST LAB
(LM/DENVER)

Software Development

- ✓ Flight Software load 28A released on 9/14/17 (Nominal Mission including On-Orbit, CM Fault Detection Isolation and Recovery (FDIR) except prop)
- ✓ Flight Software load 28B released on 12/19/17 (CM prop FDIR, EM-1 Onboard Network Config, Solar Array Control)
- ✓ Flight Software load 28C released 3/08/18 (Guidance, Navigation, and Control (GNC) commands, Ballistic Entry, Initial ESM FDIR, Video, Burn Plan Management)
- – Flight Software load 28D on schedule for 5/31/18 (ESM FDIR, Ascent Aborts, Initial Backup Flight Software (BFS)/Safe Mode, Optical Navigation)
- – Flight Software load 28E on schedule for 8/23/18 (Full GNC SM FDIR, BFS/Safe Mode, Redundancy Management)

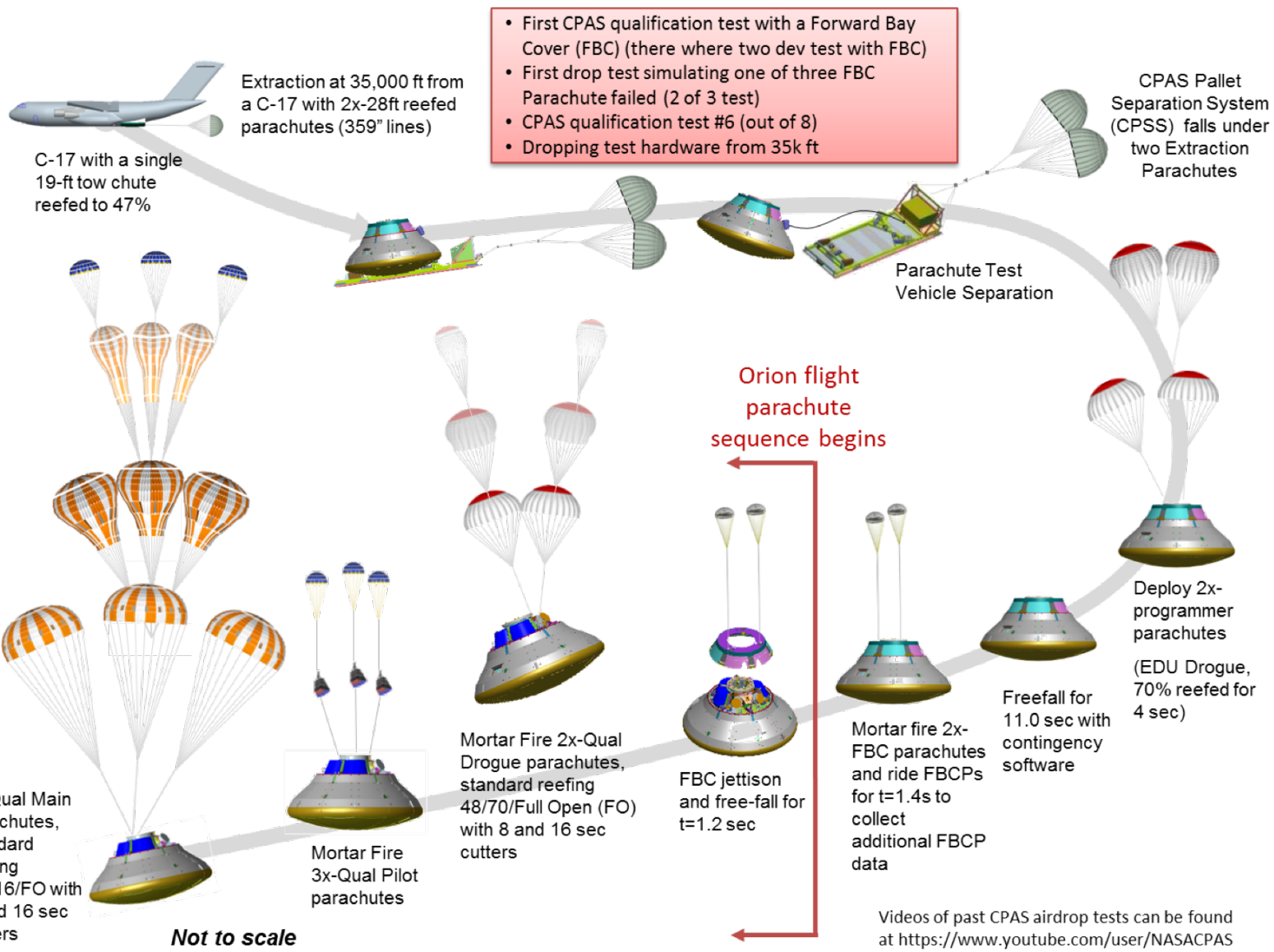
✓ 28A/B FSW Released	✓ 28C FSW Release	28D FSW Release	28E FSW Release	28F FSW Release	28G FSW Release

Integrated Test Lab (ITL)

- ✓ Completed 18 Nominal, Off Nominal and FDIR mission tests thru 2017
- ✓ ITL-03 CM Subsystem Integration & Assembly, Test, and Launch Operations (ATLO) Check out (C/O) ITL gap testing complete - February 2018
- – ATLO IPO & CSM 28D functional testing complete - August 2018
- – ATLO mission & CSM 28E testing complete - November 2018
- – CSM 28F testing complete - February 2019
- – ITL Test Campaign verification testing complete - May 2019

✓ Gap testing	28D functional testing	28E mission testing	CSM testing complete	ITL Test Campaign Verif complete

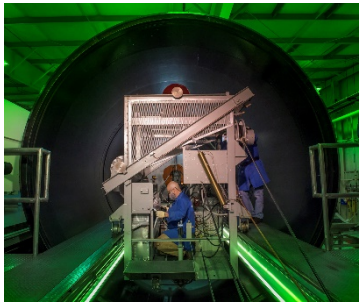
CAPSULE PARACHUTE ASSEMBLY SYSTEM (CPAS) CQT4-6 TEST CONOPS



Videos of past CPAS airdrop tests can be found at https://www.youtube.com/user/NASACPAS

SLS

EM2



EM-2 forward and center-forward booster segments

EM-2 Core Stage Engine Section

EUS RL-10 EngineP7001 Injector LO2 Plate

EUS RL-10 Engine P7001 Chamber Structural Jacket

EM-1 ICPS/MSA/LVSA

(MSFC/ULA-DECATUR)

- ✓ EM-1 Interim Cryogenic Propulsion Stage (ICPS) ship to United Launch Alliance at Cape Canaveral Air Force Station for final outfitting
- ✓ EM-1 ICPS Delivery to KSC - July 2017 (store in Space Station Processing Facility)
- ✓ EM-1 ICPS Hardware Acceptance Review - Oct 2017
- ✓ EM-1 OSA Production Complete - January 2018
- – Orion Stage Adapter (OSA) Delivery to KSC - March 2018 (U/R)
- – Launch Vehicle Stage Adapter (LVSA) Thermal Protection System (TPS) application complete - March 2018
- – EM-1 LVSA Production Complete - August 2018
- – LVSA Delivery to KSC - September 2018

ICPS in SSPF

LVSA preps for Insulation

OSA in bracket installation

EM-1 STAGES
(BOEING - MAF)

Forward Skirt
- Barrel Weldment
- Structural Assy.
- TPS App.
- Integration
- Forward Join

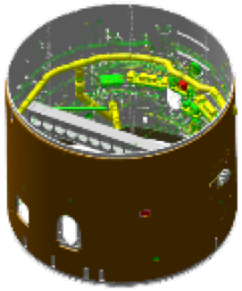
ECD April

LOX Tank
- Barrels Welded
- Domes Welded
- VAC Welding
- Hydrostatic Proof
- NDE/Baffle Install
- Clean (int/ext)
- Sensor Install
- TPS App.
- Sensor Install
- Sump Install
- Cover Install & TPS Closeout
- Forward Join

ECD March

Intertank
- Panels & Thrust Beam Fabricated
- Structural Assy.
- TPS App.
- Integration
- Forward Join

ECD April

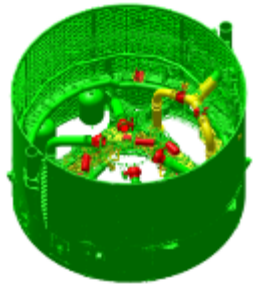


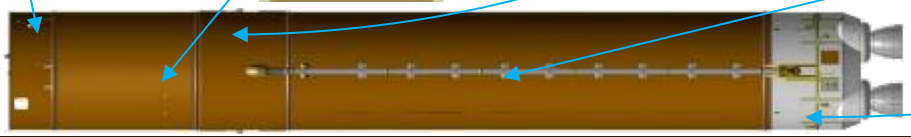
LH2 Tank
- Barrels Welded
- Domes Welded
- VAC Welding
- Pneumatic Proof
- NDE
- Clean (int/ext)
- Sensor Install
- TPS App.
- Sensor Install
- Manifold Prep
- Covers Install & TPS Closeout
- Aft Join

ECD March

Engine Section
- Barrel Weldment
- Thrust Struct. Assy.
- ES Structural Assy.
- Integration
- Boat Tail Stack
- Aft Join

ECD June (UR)



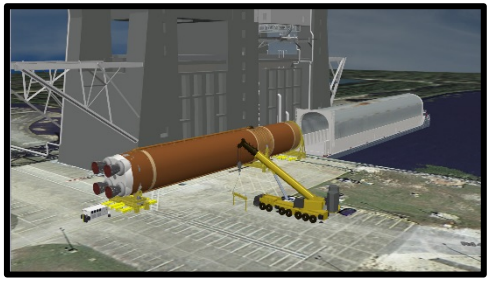


Complete
In-Work/Next
Not Started

- ☑ Weld Confidence Articles
- ☑ All CS-1 VAC Complete
- ☐ FS Complete
- ☐ IT Complete
- ☐ LOX Tank Complete
- ☐ Forward Join
- ☐ LH2 Tank Complete
- ☐ ES Complete
- ☐ Aft Join
- ☐ Final Join

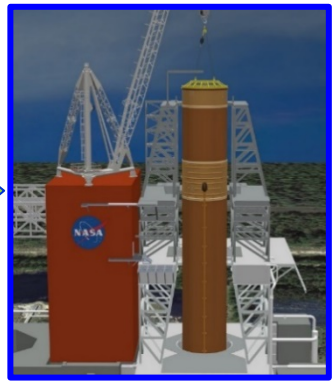
CORE STAGE GREEN RUN

Pegasus Barge Transports CS1
To SSC From MAF



Prep on the Tarmac
For Loading into B-2 Stand

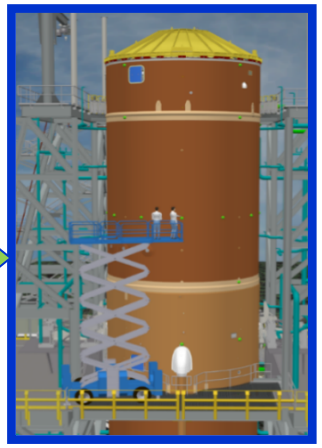
2 Crane Lift Into B-2 Stand



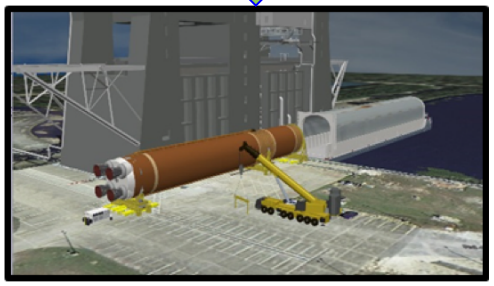
Test 1: Modal Test (Suspended)
Test 2: Vehicle Power-On Checks
Test 3: MPS/Engine Leak Checks
Test 4: Hydraulics and TVC Checks
Test 5: Safing Checks for Wet Dress Rehearsal
Test 6: Simulated Countdown and Hot Fire Test
Test 7: Wet Dress Rehearsal

Test 8: Hot Fire CS1

62 Boeing Con-Ops Procedures While at SSC

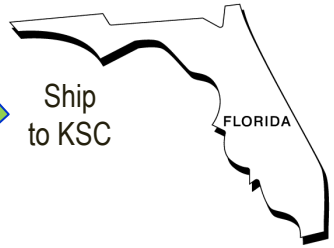


Test 9: Refurbish in Stand



Prep on the Tarmac
For Loading into Pegasus

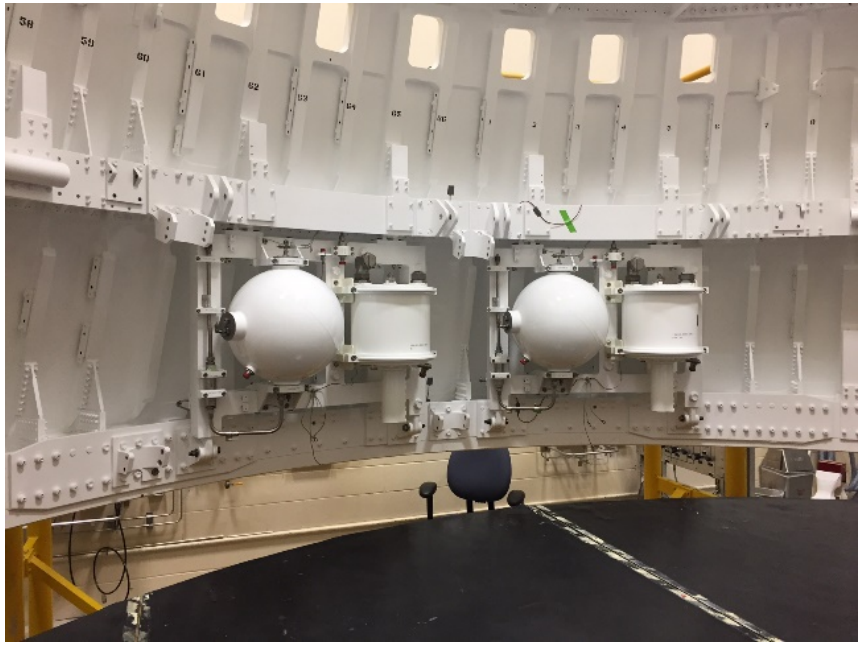
Ship
to KSC



EM-1 BOOSTERS

(ATK - UTAH)

- ✓ All Booster Separation Motors are cast and finalized
- ✓ EM-1 Left & Right Hand Booster Production progressing
- ✓ All EM-1 Segment Casting complete
- ✓ Both Aft skirts structural refurbishment complete
- ✓ Both EM-1 Nozzle assemblies and Aft Exit Cones complete
- ✓ Avionics Qualification Testing Complete - October 2017
- ✓ EM-1 Left Hand aft skirt TVC lower frame installation complete
- ✓ 4 of 10 EM-1 Segments Finalized and in Storage (*see note below*)
- – Propellant-liner-insulation (PLI) complete - April 2018
- – EM-1 PLI Waiver signed – September 2018
- – EM-1 Segments Ready to Ship - November 2018



Thrust Vector Control Installation Progress in EM-1 Left Hand Aft Skirt

Note: Flight worthiness of first 6 segments to be determined by leveraging the learning obtained during flight rationale development for EM-1

EM-1 ENGINES

(AR - SSC)

- ✓ Held RS-25 Production Re-start Integrated Baseline Review (IBR) - May 2016
- ✓ Engine 0528 RS-25 (LOX Pump Pressure) Complete - Feb 2017
- ✓ Engine Control Unit (ECU) Flight Model (FM) -1 to 3 ATP Complete - Apr 2017
- ✓ Engine 0528 ECU Green Run Testing Complete
- ✓ EM-1 RS-25 Engines Deliver in Place - Oct 2017
  - *The EM-1 Flight Engines are Engine 2045, Engine 2056, Engine 2058, and Engine 2060*
- ✓ ECU Qualification Complete - Nov 2017
- ✓ Completion of three RS-25 Production Restart Development Hot Fire Testing Begins - Dec 2017 through Feb 2017
  - ✓ Includes successful testing of first major additive manufactured component: Pogo device
- – 1st EM-2 (EM-1 spare) Engine (2063) Complete - August 2018

Final Engine Adaptation / Software Cert Hot-fire Test

All 4 EM-1 Engines Delivered-in-place

Software Test Lab
(MSFC)

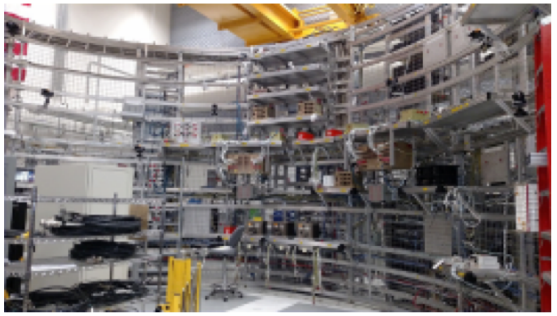
Software

- ✓ Deliver Flight Software Release 13 - December 2016
- ✓ Complete Sprint 5 Flight Software Release 14 - March 2017
- ✓ Complete Sprint 6 (final sprint) Flight Software Release 14 - May 2017
- – Complete Release 14 Green Run Application Software (GRAS) - April 2018
- – Complete Release 14 Flight Control Application Software (FCAS) - November 2018

☑ FSW 11 Release (Engineering)	☑ FSW 12 Release (Engineering)	☑ FSW 13 Release	☐ FSW 14 Release (GRAS)	☐ FSW 14 Release (FCAS)

Software Integration Test Facility (SITF) - Qualification Testing

- ✓ Complete Phase 1 (Pwr Quality & Verif) - May 2016
- ✓ Complete Phase 2 (Command and Data Handling (C&DH) & Flight Safety System (FSS) Dry Run) - October 2016
- ✓ Complete Phase 3 (Flt Ctrl & Telemetry (TLM) Dry Run) - June 2017
- – Complete Phase 4 (Final Avionics Verif) - June 2018



SITF Qualification Testing

☑ SITF Development	☑ SITF Qual Test Ph 1 Comp	☑ SITF Qual Test – Ph 2 Comp	☑ SITF Qual Test – Ph 3 Comp	☐ SITF Qual Test Complete

EGS

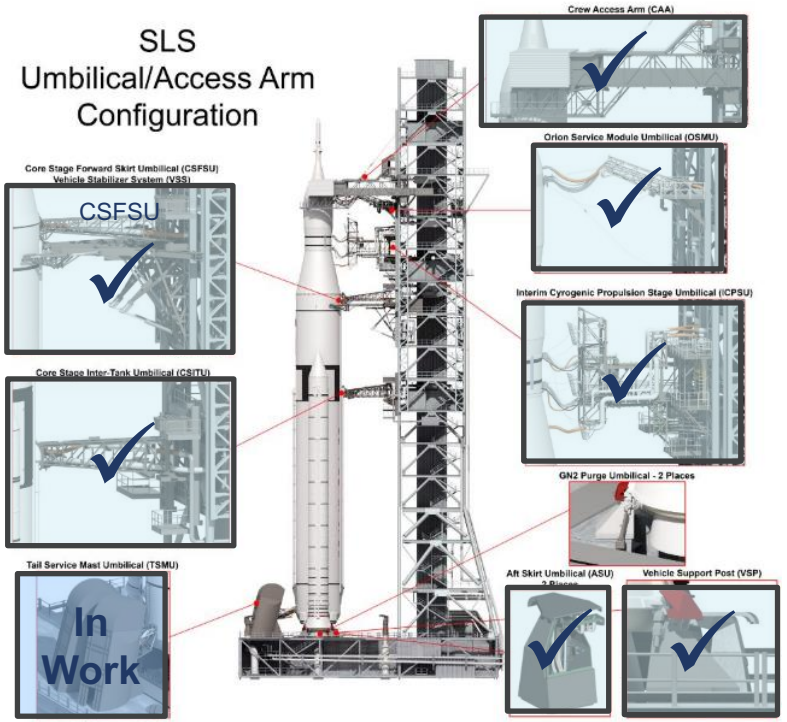
UMBILICAL LETF TESTING/MOBILE LAUNCHER

(LETF - KSC)

- ✓ Crew Access Arm (CAA) Installed – February 2018
- ✓ Interim Cryogenic Propulsion Stage Umbilical (ICPSU) Testing is complete; Ready to deliver to ML - February 2018
- ✓ LO2 TSMU Testing is complete; Ready to deliver to ML - February 2018
- − LH2 TSMU Testing is underway; Ready to deliver to ML - April 2018
- − ML Fit check at Pad – June 2018
- − ML Roll to VAB
- − ML/Pad Multi-element V&V

EM-2 Development

- − Design requirements for modification to ML for SLS Block 1B have been released to the Architect Engineer (A&E) (RS&H)

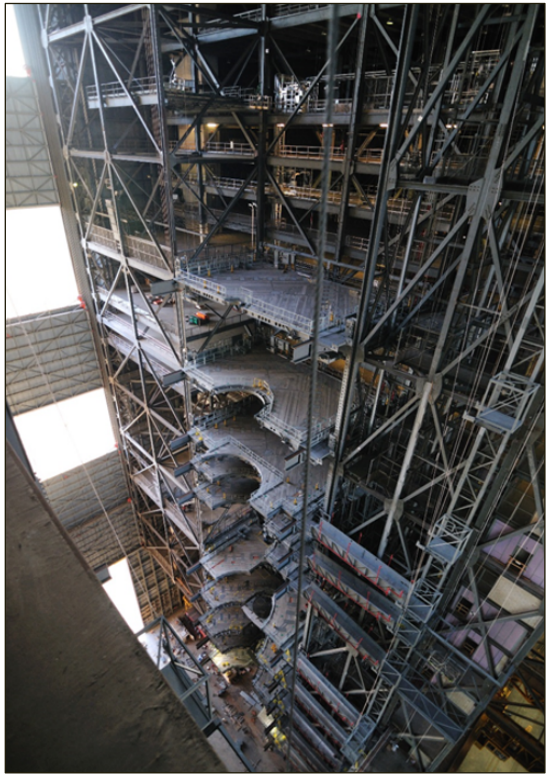


✓ Crew Access Arm (CAA) Installed	✓ Interim Cryo Propulsion Stage Umbilical (ICPSU)	✓ LO2 Tail Service Mast Umbilical (TSMU)	LH2 TSMU	ML Fit Check at Pad	ML Roll to VAB	ML/Pad multi element V&V

VAB
(KSC)

EM-1 Progress

- ✓ All vehicle access platforms have been installed and outfitting is complete
- ✓ VAB High Bay (HB) 3 elevators are complete
- ✓ GSE Handling and Access (H&A) fabrication and installation is complete
- ✓ Fire Alarm/Firex System Acceptance Testing is complete
  (During Firex wet flow testing, the measured flow rates did not meet required values in two out of four zones; Follow on work to replace legacy valves and sprinklers to meet new pump pressure and continue mock-up testing with new nozzles)
- – Work on the Environmental Control System (ECS) continues; expected completion in March 2018



EM-2 Development

- – VAB ECS and HB 3/4 design continues
  - ✓ ECS 30% design review held January 17th
  - ✓ HB 3/4 30% design review held January 18th

PAD 39B
(KSC)

EM-1 Progress

- ✓ Overall Pad B development is progressing well
- ✓ Ignition Over Pressure and Sound Suppression (IOPSS) Wet Flow Testing complete December 2017
- ✓ LH2 Liquid Gas Separator 100% complete
- – Flame Trench/ Deflector is 84% complete
- – Environmental Control System (ECS) refurbishment is 97% complete
- – LO2 & LH2 Cryo Spheres fills are in progress to complete by April 2018

IOPSS Wet Flow Test

EM-2 Development

- – LH2 Storage Tank Design is over 60% complete
  - – A&E Final Submittal expected in February 2018; Construction procurement activities will follow

Flame Deflector

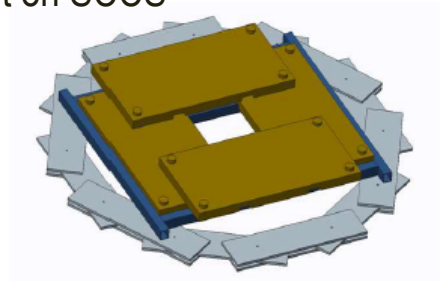
MULTI-PAYLOAD PROCESSING FACILITY (MPPF)
(KSC)

MPPF standalone V&V activities are underway

- ✓ Crew Module Ammonia Servicing Subsystem (CMASS), Gaseous Nitrogen (GN2), Gaseous Oxygen (GO2), Gaseous Helium (GHe), and Kennedy Complex Control System (KCCS) V&V activities are complete
- ✓ Orion Transportation Pallet (OTP) was received and V&V is complete
- ✓ Ground Cooling System V&V Test Readiness Review completed - February 2018

- Hypergol Servicing/Deservicing testing is dependent on SCCS 4.0.1 validation
  - Cold Flow start targeted for March 2018
  - Hot Flow start targeted for May 2018
  - V&V complete expected in June 2018
- Done MPPF until Vehicle Processing

CSM Simulator in Servicing Stand



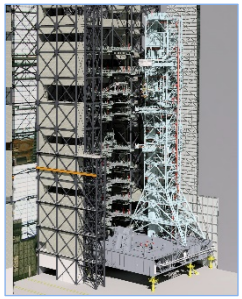
Weight Simulation to be placed on OTP in 2018

SCAPE Ops Training

Spaceport Command & Control System (SCCS)

- SCCS 4.0.1 - Hazardous Testing & GFAS Development/Test
- SCCS 5.0 – Orion flight vehicle processing & GFAS V&V
- SCCS 6.0 – GFAS Regression, ITCO, WDR and EM-1

MPPF Hazardous Testing



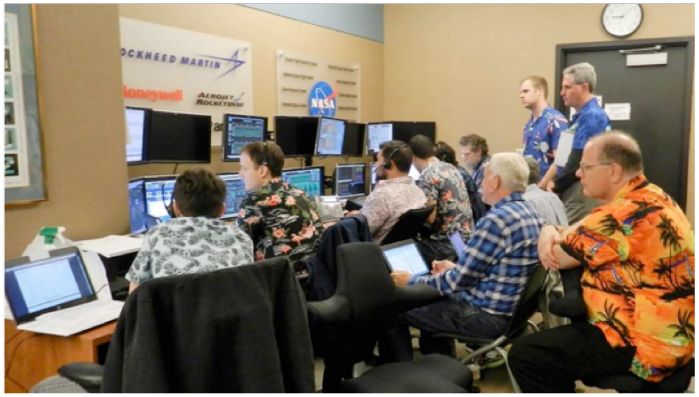
MEVV @ VAB

MEVV @ Pad

- SCCS 4.0 complete and transitioning to 4.0.1 in Firing Rooms (Feb 2018)
- SCCS 4.0.1 – System Test on schedule for planned start (Feb 2018)
- Validation complete (Mar 2018)

☑ SCCS 4.0 Validated Release	☐ SCCS 4.0.1 System Test	☐ SCCS 4.0.1 Validated	☐ SCCS 5.0 Engineering Release	☐ SCCS 5.0 Validated	☐ SCCS 6.0 Engineering Release	☐ SCCS 6.0 Validated

Ground Flight Application Software (GFAS)



- Completed initial GFAST testing at ITL & SIL with favorable results
- Continued prioritization of partnered cross program initiatives, challenges and deliverables

☑ GFAS Drop 10 & 11	☑ GFAS (ECLSS/Hypers) V&V Complete	☐ GFAS Ready for ML/Pad ME V&V	☐ GFAS SC Offline Ready (SAR)	☐ GFAS ITCO Ready (SAR)